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PORTABLE UNIVERSAL FRICTION TESTING MACHINE AND METHOD

FIELD OF THE INVENTION

5 The invention herein described relates generally to friction test machines and methods and, more particularly, to a friction testing machine and method for measuring the coefficient of friction between a rubber specimen or a tread element and different friction surfaces at different speeds, contact pressures and orientations.

BACKGROUND OF THE INVENTION

10 When developing new compounds for tires, a prior practice was to build a tire and subject the tire to various traction tests. Because of the cost and time needed to build test tires for the purpose of optimizing traction properties, small
15 samples of tread compounds have instead been used to determine the traction characteristics of the compounds. By using small samples for testing, a large number of different tread compounds can be made in small batches for screening to determine which compound has the best properties. The small samples could also be tested with different friction test surfaces representing different road
20 surfaces and different conditions, whereby the traction properties of the compounds may be observed to determine which compound has the best traction on a specific road surface under specific conditions.

 In U.S. Patent No. 5,113,688 there is disclosed an apparatus and method for predicting tire traction characteristics of tread compounds using small test
25 samples. The apparatus causes a rotating relationship between the sample and friction surface. The torque between the sample and friction surface is measured and a torque versus time curve is established for the sample. Such apparatus, however, does not appear to be easily movable as may be desired for testing at different locations, nor is such apparatus suitable for evaluating the performance
30 of different tread patterns. It would be advantageous to have a portable friction testing apparatus that not only can measure the coefficient of friction of plain tread elements, but also can measure the coefficient of friction of tread blocks,

shoulders, etc., of existing tires. A further desirable advantage would be an apparatus that permits one to view the interaction between the friction surface and the specimen in the same way as the present invention.

SUMMARY OF THE INVENTION

The present invention provides a friction testing machine and method for measuring friction characteristics between a test sample and a friction surface. The machine and method are particularly suited for measuring the coefficient of friction between a rubber specimen or a tread element and different friction surfaces at different sliding velocities, contact pressures and orientations. A preferred embodiment of machine is self-contained and portable, configured for easy and quick changing of the friction surface, and provides for rotating the test sample about an axis normal to the sliding surface and the direction of movement of the sample relative to the friction surface.

In general, a friction test machine according to the invention comprises a sample holder configured to hold a sample in frictional engagement with a friction surface, and a motion device for effecting relative movement between the friction surface and sample holder in a first direction. Also provided is a variable weight loading device on the sample holder for loading the sample holder such that a selected load can be applied to the sample normal to the friction surface, and a force measurement device for obtaining a measurement indicative of the frictional force resisting such relative movement between the sample holder and the friction surface effected by the motion device.

Preferably, there is provided a second motion device for effecting relative movement between the sample holder and friction surface in another direction different than the first direction, such as rotation about an axis perpendicular to the friction surface and/or translation in a direction transverse to the primary direction of movement.

In one embodiment of friction test machine according to the invention, there is provided a base on which the friction surface is supported, and a carriage mounted on the base and guided for movement in a first direction parallel to the

friction surface. The motion device is connected between the carriage and base for moving the carriage in the first direction, and the sample holder is mounted to the carriage for movement therewith and configured to hold the sample in frictional engagement with the friction surface during movement of the carriage in the first direction. In another embodiment of the friction test machine, the motion device causes relative movement between the carriage and the friction surface in a second direction opposite to the first direction so that the force measurement device can obtain measurements indicative of the frictional force in forward and reverse directions.

10 Preferably, the friction surface is provided on a friction element, and the friction element is removably supported on the base, whereby the friction element can be interchanged with other friction elements for providing respective different friction surfaces. In a preferred embodiment, the base includes a recess for removably holding the friction element, and the base is supported on a cart for
15 easy transport of the machine from place to place.

In another embodiment of friction testing machine according to the invention, there is provided a carriage fixed to the base, and the sample holder is mounted in the carriage for vertical movement perpendicular to the friction surface. A table is mounted to the base for rotation about a vertical axis, and the
20 friction surface extends annularly around a radially outer peripheral portion of the table, whereby the friction surface is moved while the sample remains stationary.

In still another embodiment of friction testing machine according to the invention, there is provided a base adapted to rest on a surface against which a sample is to be tested, such as a road surface. A carriage is mounted on the
25 base and guided for movement in a first direction parallel to the friction surface. A motion device is connected between the carriage and base for moving the carriage in the first direction, and a sample holder is mounted to the carriage for movement therewith and configured to hold the sample in frictional engagement with the friction surface during movement of the carriage in the first direction.

30 Preferably, the base is provided with an aperture through which the sample holder

extends for positioning the sample against the friction surface disposed beneath the base.

In a preferred embodiment of the invention, the variable weight loading device includes a weight platform on which removable weights can be stacked and removed to selectively vary the load applied to the sample. Alternatively, the variable weight loading device comprises a fluid cylinder that is controlled by the processor to vary the load applied to the sample. It also is preferred to provide the friction surface on a friction element that is easily and quickly interchangeable with other friction elements for providing respective different friction surfaces.

In a preferred embodiment of the invention, a temperature chamber encloses the friction surface and the sample whereby temperature can be controlled to simulate different temperature conditions. Additionally or alternatively, the machine includes a water source and a pump which transfers water from the source onto the friction surface whereby the measurement device can obtain measurements indicative of the frictional force in wet conditions.

In a preferred embodiment of the invention, a processor controls the motion device, controls the variable weight loading device, controls the temperature chamber, and/or records the measurements obtained by the force measurement device. The processor further analyzes the measurements and compiles the results in the form of tables and/or graphs and an output device is provided to allow a readout of the compiled results. Preferably, the processor provides a library of pre-defined tests and a selection device for selecting a particular test.

The present invention accordingly provides a method of predicting tire traction characteristics of a tread component. The method comprises the steps of preparing a sample of the tread component; attaching the sample to the sample holder, setting the variable weight device to apply a certain load to the sample, and using the force measurement device for obtaining a measurement indicative of the frictional force resisting such relative movement between the sample holder and the friction surface effected by the motion device. During this method, the

friction surface may be replaced with another different friction surface to predict tire traction characteristics with respect to different road surfaces. Also, water may be transferred onto the friction surface to gather measurements indicative of the frictional force in wet conditions. The temperature surrounding the friction surface and the sample may be controlled to simulate different temperature conditions, such as winter conditions and summer conditions.

The foregoing and other features of the invention are hereinafter fully described and particularly pointed out in the claims, the following description and the annexed drawings setting forth in detail one or more illustrative embodiments of the invention, such being indicative, however, of but one or a few of the various ways in which the principles of the invention may be employed.

BRIEF DESCRIPTION OF THE DRAWINGS

Fig. 1 is a schematic side elevation view of a portable friction testing machine according to the invention.

Fig. 2 is a schematic plan view of the portable friction testing machine of Fig. 1.

Fig. 3 is a partial sectional view taken along the line 3-3 of Fig. 1 showing details of a representative friction block used in the machine.

Fig. 4 is a schematic plan view of another embodiment of portable friction testing machine according to the invention.

Fig. 5 is a schematic side elevation view of the portable friction testing machine of Fig. 3.

Fig. 6 is a schematic side elevation view of a further embodiment of portable friction testing machine according to the invention.

Fig. 7 is a schematic plan view of the portable friction testing machine of Fig. 6.

Fig. 8 is a schematic side view of another embodiment of a portable friction testing machine according to the invention.

Fig. 9 is a schematic side plan view of another embodiment of a portable friction testing machine according to the invention.

Fig. 10 is a schematic top view of the portable friction testing machine of Fig. 9.

DETAILED DESCRIPTION OF THE INVENTION

5 Referring now in detail to the drawings and initially to the embodiment of the invention shown in Figs. 1-3, a portable friction testing machine according to the invention is schematically shown at 20. The machine 20 comprises a base 22 in the form of a plate. In the embodiment illustrated in Figs. 1-3, the base 22 has a length several times longer than its width and is supported atop a cart 24 that
10 may be equipped with wheels, such as casters 25, for easy transport from one place to another. As diagrammatically shown, the cart 24 also carries, for transport with the other components of the machine 22, electronic components 26 including a processor 28. The processor 28 can be a conventional microcomputer suitably programmed to carry out the various control and
15 processing functions of the machine. As will be appreciated, the machine may be otherwise supported and configured, preferably for easy portability. For example, the machine alternatively may be supported on a table top and the base may be equipped with handles for convenient lifting of machine for transport from one table to another.

20 As best seen in Fig. 3, the base 22 includes a recess 36 for receiving a friction element in the form of a block 38. The friction block 38 includes a holder 40 for containing a friction material 42 that has an exposed top or friction surface 44. The holder 40 and recess 36 are corresponding sized and configured to prevent any significant horizontal shifting of the holder relative to the platform
25 while permitting easy removal of the friction block from the base as by lifting the friction block out of the recess in the base. This enables easy and quick interchanging of different friction blocks having different friction surfaces, as may be desired for testing a particular sample on different friction surfaces. The friction surfaces can be composed of different materials and/or textures. As will
30 be appreciated, the friction block may be entirely formed of a single material in which case the holder and friction material are integral with one another.

Preferably, the friction surface 44 is planar and flush with the top surface 46 of the base 22 and extends parallel to the longitudinal axis of the base 22 about approximately half the length of the base. Like the base, the friction surface has a length several times longer than its width.

5 The friction surface 44 may be any one of a variety of different surfaces. The surface may be composed of asphalt, concrete, snow, etc. and the surface may have different textures, for example rough, smooth, grooved, etc. If desired, the friction surface may have different characteristics along the length thereof, as is desirable for measuring friction characteristics of the sample as it transitions
10 from one surface to another. For example, the first half of the friction surface may be composed of asphalt and the second half may be composed of concrete. The friction block can also be transparent to enable viewing of the sample as it moves across the friction surface. For example, the friction block can be made of glass or plexiglass having a friction surface formed by texturing, by a wire mesh on top
15 of the glass or plexiglass substrate, etc. A camera, particularly a high speed camera, can be mounted beneath the friction block to view and record the dynamic action of the sample as it moves across the friction surface.

The base 22 has mounted thereon a vertical support plate 50 which, in the illustrated embodiment, extends approximately half the length of the base 22.
20 The vertical support plate 50 has at opposite ends thereof in-turned mounting arms 52 and 54. Connected to and extending between the mounting arms are a pair of guides 56 in the form of rods on which a carriage 58 is mounted and guided for movement along the length of the friction surface. The carriage preferably is equipped with suitable bearings for relatively friction-free sliding on
25 the guide rods.

The carriage 58 carries a sample holder 62. The sample holder 62 includes a post 64 that is guided by suitable bearings in the carriage 58 for vertical movement perpendicular to the friction surface. Attached to the lower end of the post 64 is a sample mount 66 to which a sample S can be removably
30 attached by suitable means.

Attached to the upper end of the post 64 is a weight platform 68 on which weights W can be removably stacked to selectively vary the load applied to the sample. Preferably, the weights are donut shape or otherwise have a center hole for slipping over the upper end of the post or other projection extending upwardly from the weight platform 68 to hold the weights W on the platform as the carriage is moved. However, other means may be employed to hold the weights in place while still permitting easy assembly or removal of the weights on or from the platform. The amount of weight set on the platform 68 determines the amount of normal force holding the sample against the friction surface 44 as the sample is moved over the friction surface. Preferably, a lifting device 70 is provided to lift the sample S off of the friction surface for changing of the sample S and/or friction surface 44 during testing procedures.

Movement of the sample S over the friction surface 44 is effected by a motion device 76. In the illustrated embodiment, the motion device includes a motor 78 which rotates a lead screw 80 for linearly moving a drive carriage 82 along the longitudinal axis of the base 22. The drive carriage 82 is connected to the specimen holder 66 or carriage 58 by a connecting member 84 for moving the specimen holder along with the drive carriage. In the illustrated embodiment, the connecting member 84 is a rod connected by a ball joint 86 at one end to the drive carriage and by a ball joint 88 at its opposite end to the specimen holder 66. The ball joints 86 and 88 accommodate slight misalignments between the specimen holder/carriage path and the drive carriage path. The drive motor 78 can be operated in either direction for moving the specimen holder over the friction surface in opposite directions. Moreover, the drive motor can be operated at different speeds to provide a large range of sliding velocities. For example, when measuring the coefficient of friction of a tread compound, the motor can be operated at sliding velocities comparable to what a tire experiences in service. For example, translation speeds in the range of zero to about 4.0 inches/second can be obtained. As will be appreciated, other connecting members can be used, such as a wire to pull the specimen holder/carriage in one direction over the friction surface.

The drive carriage 82 has secured thereto a force measurement device 92, such as a load cell, which measures the horizontal force at the footprint of the sample. It is the load cell 92 to which the connecting rod 88 is connected by the ball joint 86. As the drive carriage moves the sample holder 66 over the friction surface 44, the load cell will output a signal indicative of the frictional force
5 resisting movement of the sample across the friction surface. The output of the load cell is connected to a data acquisition system 94. More particularly, the output of the load cell 92 is connected by a shunt calibrator 96 to a charge amplifier 98 which in turn is connected to the processor 28. As those skilled in
10 the art will appreciate, the shunt calibrator is provided for easy calibration of the system. The processor 28 processes the output of the sensor to provide a measurement of the friction characteristics, e.g., coefficient of friction, of the sample S being tested for the selected friction surface.

In the case of a tread element, for example, it may be desirable to
15 measure the coefficient of friction in different directions. To this end, the sample holder 66 can be rotated about its vertical axis (normal to the friction surface) in the carriage 58 and then fixed by suitable means at a selected angle of rotation.

For some tests, It is desirable to give the sample two independent translations in two orthogonal directions, a translation and rotation, or both. The
20 linear movement of the sample S across the friction surface effected by the motor 78 constitutes translation in one orthogonal direction. To obtain translation in a second orthogonal direction, there is provided a transverse drive mechanism 100 for moving the sample holder transversely back and forth relative to the linear movement direction of the carriage. To obtain rotation about an axis
25 perpendicular to the friction surface, a rotation mechanism 102 is provided for rotating the sample holder during movement of the sample linearly across the friction surface. Preferably, the transverse drive mechanism 100 and rotation mechanism 102 are housed in the carriage 58, as diagrammatically depicted in Fig. 1, and operate on the post 64 for effecting transverse and rotational
30 movement of the sample holder 66. For example, the rotation mechanism 102 can be a motor and suitable gearing and/or other drive components for rotating

the sample holder in a controlled manner. For some tests, it may be desirable to reciprocally rotate the sample back and forth as it is moved along the friction surface. Similarly, the transverse drive mechanism 100 can be a motor and suitable gearing and/or other drive components for moving the sample holder transversely to the direction of movement of the carriage along the length of the friction surface. If the sample holder 66 is undergoing rotational or transverse movement during testing, then preferably the connecting member 84 is connected to the carriage 58, and thus indirectly to the sample holder instead of directly to the sample holder 66.

Tests can also be conducted under wet conditions. To this end, water can be applied to the friction surface 44 by a tube 108 connected to a reservoir 110 or other source of water. In the illustrated embodiment, a pump 112 is used to pump the water onto the friction surface 44 at a desired rate or when needed. A suitable drain 114 (Fig. 3) is preferably provided, for example at the bottom of the recess 36 in the base 22, for removing water from the test area and, if desired, recycling the water back to the reservoir 110 as shown in Fig. 1. For wet tests, the friction block preferably is provided with suitable drain passages, as along the edges thereof for channeling the water to the drain, as opposed to the water flowing over the top surface of the base. However, it will be appreciated that the base alternatively or additionally may be configured for collection of the water being applied to the friction surface. Also, a distribution member, such as a manifold with multiple outlets spaced along the length of the friction surface, can be employed for more even distribution of water over the friction surface.

Referring now to Figs. 4 and 5, another embodiment of portable friction testing machine according to the invention is schematically shown at 120. The machine 120 comprises a base 122 supported on or in the form of a cart 124 that may be equipped with wheels, such as casters, for easy transport from one place to another. Like in the above described testing machine 20, the cart 124 preferably carries, for transport with the other components of the machine 122, electronic components 126 including a processor 128. As before, the processor

128 can be a conventional microcomputer suitably programmed to carry out the various control and processing functions of the machine.

The base 122 has mounted thereon a table 132 that rotates about a vertical axis. The table is driven by a motion device 134 including, for example, a motor 136 and suitable controls for controlling the speed of the motor. The outer peripheral annular edge portion of the table is covered by a friction surface preferably provided by a removable annular friction element 138. The removable friction element 138 is in the form of an annular disc-like holder for containing a friction material that has an exposed annular top or friction surface 144. The annular friction element 138 is concentric with the rotation axis of the rotating table 132 and is suitably secured to the rotating table by suitable means for rotation therewith. Preferably, the friction element is removably secured for permitting easy and quick interchanging of different friction elements having different friction surfaces, as may be desired for testing a particular sample on different friction surfaces. As before, the surfaces can be composed of different materials and/or textures, such as those above mentioned.

The base 122 has mounted thereon a carriage 158 located above the friction surface 144 on the rotating table 132. The carriage 158 has mounted therein a sample holder 162 which includes a post 164 that is guided by suitable bearings in the carriage 158 for vertical movement perpendicular to the friction surface 144. Attached to the lower end of the post 164 is a sample mount 166 to which a sample S can be removably attached by suitable means. Attached to the upper end of the post is a weight platform 168 on which weights W can be removably stacked to selectively vary the load applied to the sample, as in the manner described above in connection with the testing machine 20. The amount of weight set on the platform 168 determines the amount of normal force holding the sample against the friction surface as the sample is moved over the friction surface.

As will be appreciated, movement of the sample S relative to the friction surface 144 is effected by rotating the table 132. The drive motor 136 can be operated in either direction for moving the friction surface relative to the sample in

opposite directions. Moreover, the drive motor can be operated at different speeds to provide a large range of sliding velocities, such as the above mentioned range. The rotating table preferably is of a sufficiently large diameter that the sample in essence is moving linearly relative to the friction surface, this
5 essentially being equivalent to the linear translating movement of the sample in the testing machine 20.

The sample mount 166 includes a force measurement device 192, such as a load cell, which measures the horizontal force at the footprint of the sample S parallel to the movement direction of the sample relative to the friction surface
10 144. As the motor 136 moves the friction surface 144 underneath the sample holder 158, the load cell 192 will output a signal indicative of the frictional force resisting movement of the sample across the friction surface. The output of the load cell is connected to a data acquisition system as above described.

As above indicated, it may be desirable to measure the coefficient of
15 friction in different directions. To this end, the sample holder 166 can be rotated about its vertical axis (normal to the friction surface) in the carriage 158 and then fixed by suitable means at a selected angle of rotation.

Again, for some tests, It is desirable to give the sample two independent translations in two orthogonal directions, a translation and rotation, or both. The
20 movement of the rotating friction surface 144 beneath the sample S essentially constitutes translation in one orthogonal direction. To obtain translation in a second orthogonal direction, a transverse drive mechanism 200 for moving the sample holder transversely back and forth relative to the linear movement direction of the carriage. To obtain rotation about an axis perpendicular to the
25 friction surface, a rotation mechanism 202 is provided for rotating the sample holder relative to the carriage while the friction surface is moving beneath the sample. Preferably, the transverse drive mechanism 200 and rotation mechanism 202 are housed in the carriage 158 as diagrammatically depicted in Fig. 5.

Figs. 6 and 7 show a further embodiment of portable friction testing
30 machine according to the invention. The machine 320 is substantially the same as the above described machine 20, except that it modified as discussed below to

provide for *in situ* testing of a friction surface, such a floor surface or roadway surface. Thus, the electronic components of the machine 320 are the same as above described in connection with machine 20, although the processor is not shown in Figs. 6 and 7.

5 Like the machine 20, the machine 320 comprises a base 322 in the form of a plate. The base 322 is adapted to rest atop the friction surface 344 against which a sample is to be tested. If desired, the base may be carried by a cart (not shown) that may be equipped with wheels, such as casters, for easy transport from one place to another. The cart may be equipped with a mechanism for
10 lowering the base, when testing is desired, to a position adjacent a friction surface on which the cart is supported. As will be appreciated, the machine may be otherwise supported and configured, preferably for easy portability. For example, the machine alternatively may be equipped with handles for convenient lifting of machine for transport from one place to another.

15 The base 322 includes an aperture and more particularly an elongated through opening 336 for permitting access to the underlying friction surface by a sample S in a sample holder 362. The sample holder 362 includes a post 364 that is guided by suitable bearings in a carriage 358 for vertical movement perpendicular to the friction surface. Attached to the lower end of the post 364 is
20 a sample mount 366 to which the sample S can be removably attached by suitable means. As seen in Fig. 6, the sample holder (including the sample) extends through the opening 336 in the base for engagement with the friction surface underlying the base.

 The upper end of the post 364 is provided with a weight platform 368 on
25 which weights W can be removably stacked to selectively vary the load applied to the sample. As in the case of the machine embodiment of Figs. 1 and 2, the amount of weight set on the platform 368 determines the amount of normal force holding the sample against the friction surface as the sample is moved over the friction surface. Likewise, the base 322 has mounted thereon a vertical support
30 plate 350. Connected to and extending between mounting arms on the support plate are a pair of guides 356 in the form of rods on which a carriage 358 is

mounted and guided for movement along the length of the elongated opening 336 in the base.

Movement of the sample S over the friction surface 344 is effected by a motion device 376 including, for example, a motor 378 which rotates a lead screw 380 for linearly moving a drive carriage 382 along the longitudinal axis of the base 322. The drive carriage 382 is connected to the specimen holder 366 or carriage 358 by a connecting member 384 for moving the specimen holder along with the drive carriage. The drive motor 378 can be operated in either direction for moving the specimen holder over the friction surface in opposite directions. Moreover, the drive motor can be operated at different speeds to provide a large range of sliding velocities.

The drive carriage 382 has secured thereto a force measurement device 392, such as a load cell, which measures the horizontal force at the footprint of the sample. As the drive carriage moves the sample holder 366 over the friction surface 344, the load cell will output a signal indicative of the frictional force resisting movement of the sample across the friction surface. The output of the load cell is connected to a data acquisition system 394 as above described in connection with the machine embodiment 20 of Figs. 1 and 2. The output of the sensor provides a measurement of the friction characteristics, e.g., coefficient of friction, of the sample S being tested for the selected friction surface. As before described, the sample holder 366 can be rotated about its vertical axis (normal to the friction surface) in the carriage 358 and then fixed by suitable means at a selected angle of rotation. Additionally or alternatively, the sample may be given two independent translations in two orthogonal directions, a translation and rotation, or both. The linear movement of the sample S across the friction surface effected by the motor 378 constitutes translation in one orthogonal direction. To obtain translation in a second orthogonal direction, there is provided a transverse drive mechanism 400 for moving the sample holder transversely back and forth relative to the linear movement direction of the carriage. To obtain rotation about an axis perpendicular to the friction surface, a rotation mechanism 402 is provided for rotating the sample holder during movement of the sample linearly across the

friction surface. Preferably, the transverse drive mechanism 400 and rotation mechanism 402 are housed in the carriage 358, as diagrammatically depicted in Fig. 6, and operate on the post 364 for effecting transverse and rotational movement of the sample holder 366.

5 By way of example, the aforesaid testing machines can be used predict tire traction characteristics of a tread component. First, a sample of the tread component is prepared and attached to the sample holder in either one of the above described friction test machines. Then, one or more weights can be placed on the sample holder for loading the sample holder such that a selected load is
10 applied to the sample normal to the friction surface. The test machine is then operated to slide the sample over the friction surface while data is collected by the processor to provide measurements indicative of the frictional force resisting relative movement between the sample holder and the friction surface effected by the motion device. The resistance force can be used to calculate the coefficient
15 of friction of the sample relative to the friction surface. As above discussed, the friction surface, in the first two embodiments described above, is replaceable with different friction surfaces for predicting tire traction characteristics with respect to different road surfaces. In the third embodiment above described, the testing machine can be positioned on different surfaces, such as different roadway
20 surfaces. As will be appreciated, the testing machine can be used to determine the frictional characteristics of a sample, for example a section of an actual tire tread, in relation to a friction surface, *in situ*, for example a roadway surface.

Referring now to Fig. 8, a schematic plan view of another friction testing machine 520 according to the present invention is shown. The machine 520 is
25 similar to the machine 20 in that it includes a base 522 supported a top a cart 524 (with castors 525). However, the machine 520 may be modified to accommodate *in situ* testing by, for example, adopting a support structure similar to that of machine 320. The machine 520 includes a processor 528 which, as with the processor 28 of machine 20 discussed above, can be a conventional
30 microcomputer suitably programmed to carry out the various control functions of the machine.

The friction testing machine 520 additionally comprises a friction surface 544, a carriage 558, and a motion device 576 which causes relative movement between the carriage 558 and the friction surface 544. A force measurement device 582, such as a load cell, obtains measurements indicative of the relevant friction force during operation of the machine 520. A sample holder 566 is mounted to the carriage 558 to hold a sample S in frictional engagement with the friction surface 544 during movement of the carriage 558. Although not specifically shown in the drawing, the friction surface 544 is preferably formed in the same manner as the friction surface 44 of the machine 20. Specifically, a selected one of a plurality of friction elements is removably supported relative to the carriage 558 whereby friction elements can be interchanged to provide different friction testing surfaces.

The motion device 576 is similar to the motion device 76 in that it includes a motor 578 which rotates a lead screw 580 for linearly moving the carriage 558 and thus the sample S held by the sample holder 562. As with the motion device 78, the drive motor 578 can be operated in either direction for moving the specimen holder over the friction surface in opposite directions so that the force measurement device can obtain measurements indicative of the frictional force in forward and reverse directions. The machine 520 may additionally include a transverse mechanism 100 and/or a rotation mechanism 102 for effecting relative movement between the sample holder and friction surface in a direction different from the forward and reverse directions.

The machine 520 includes a variable weight loading device 568 on the carriage 558 loads the sample holder 562 so that a selected load can be applied to the sample in a direction normal to the friction surface 544. The preferred and illustrated variable weight loading 568 is a fluid cylinder that is moved to different positions to selectively vary the load applied to the sample. The processor 528 preferably controls the variable weight loading device whereby a fluid cylinder, as opposed to a weight platform is preferred.

The machine 520 preferably includes a temperature control chamber 700 enclosing at least the friction surface 544 and the sample S whereby temperature

can be controlled to simulate different temperature conditions. For example, the chamber can be cooled to freezing or below-freezing temperatures to simulate winter temperature conditions and/or heated to simulate summer temperature conditions. It may be noted that although in the illustrated embodiment, the chamber 700 encloses the weight platform 568, it may be instead provided with a top slot to accommodate an extension of the platform and its supporting post above the chamber. The machine 520 may additionally or alternatively include components (such as tube 508, reservoir 510, and pump 512) to transfer water onto the friction surface 544 to simulate wet driving conditions.

The processor 528 preferably controls the motion device 576 and the weight loading device 568 to apply the desired test conditions during operation. The processor 528 may also control the temperature chamber 700 and/or the wetting components. In any event, the processor 528 preferably analyzes the measurements and compiles the results in the forms of tables and/or graphs and provides a read-out of these compiled results. Preferably, the processor 528 provides a library of pre-defined tests whereby a particular test may be selected.

Referring now to Figs. 9 and 10, schematic plan and top views of another friction testing machine 620 according to the present invention is shown. The machine 620 may include a base 622 that may be supported on a mobile cart. Alternatively, the machine 620 may be modified to accommodate *in situ* testing by, for example, adopting a support structure similar to that of machine 320. The machine 620 also includes a processor 628 which, as with the processors 28 and 528 discussed above, can be a conventional microcomputer suitably programmed to carry out the various control functions of the machine.

The friction testing machine 620 has a friction surface 644 which, although not specifically shown in the drawing, is preferably formed in the same manner as the friction surface 44 of the machine 20. Specifically, the base 622 includes a recess for removable receipt of a friction element in the form of a block. In this manner, different friction elements can be easily and quickly interchanged as may be desired for testing a particular sample on different friction testing surfaces.

The base 622 includes a pair of guides 656 in the form of horizontal rods on which a drive carriage 658 is mounted and guided for movement. A sample carriage 660 is attached to the drive carriage 658 via linear bearings and the sample carriage 660 carries a sample holder 662. The sample holder 662 includes a post 664 that is guided by suitable bearings in the carriage 660 for vertical movement perpendicular to the friction surface 644. Attached to the lower end of the post 664 is a sample mount 666 to which a sample S is removably attached by suitable means. Attached to the upper end of the post 664 is a weight platform 668, similar to the weight platform 68. Although not specifically shown in the drawings, the machine 620 may also include a lifting device, such as the lifting device 70 of machine 20, to facilitate changing of the sample and/or friction surface during testing procedures. Alternatively, the fluid cylinder, such as the fluid cylinder 568 of machine 520, may be used instead and controlled by the processor 628.

Movement of the sample S over the friction surface 644 is effected by a motion device 676. The motion device 676 is especially designed to move the drive carriage 658 in a reciprocating manner repeatedly during the collection of friction data. This reciprocating approach reduces the length of the friction surface 644 necessary for the measurements and/or data from these repeated measurements can be averaged for increased accuracy.

The motion device 676 includes a motor 678 which rotates a lead screw 680 for linearly moving the drive carriage 658 along the guide rods 656. The drive motor 678 can be operated in either direction and can be operated at different speeds to provide a large range of sliding velocities. For example, when measuring the coefficient of friction of a tread compound, the motor can be operated at sliding velocities comparable to what a tire experiences in service. For example, translation speeds in the range of zero to about 4.0 inches/second can be obtained. The motor 678 is preferably controlled by the processor 628 via a motor controller 690.

The motor 678 is positioned so that the lead screw 680 is positioned parallel with and in between the guide rods 656. The sample carriage 660 has

secured thereto a force measurement device 692, such as a load cell, to measures the horizontal force at the footprint of the sample. Specifically, as the drive carriage 658 is moved by the motion device 676 in a first direction, the sample S is moved over the friction surface 644. The resistance frictional forces
5 encountered by the sample S will restrict the movement of the sample carriage 660 in the first direction whereby the force measurement device 692 must "pull" or "push" the carriage 660 to compensate for this restriction. In this manner, the device, or more particularly the load cell 692, outputs a signal indicative of the frictional force resisting movement of the sample across the friction surface 644.

10 The output of the load cell 692 is connected to the processor 628 which processes the output of the sensor to provide a measurement of the friction characteristics, e.g., coefficient of friction, of the sample S being tested for the selected friction surface.

The processor 628 preferably controls the motion device 676 during
15 operation of the machine 520. In this matter, the stepper motor 678 can be programmed to pull the specimen S over the friction surface 644 at any desired velocity as a function of time. For example, the specimen S could be pulled in such a way that its velocity first increases with time and then decreases with time. Additionally or alternatively, the stepper motor 678 can be programmed to move
20 the specimen in a reciprocating manner repeatedly (in some applications, up to several thousand times) and collect the friction data. The processor 628 preferably analyzes the measurements and compiles the results in the forms of tables and/or graphs and provides a read-out of these compiled results.

Preferably, the processor 628 provides a library of pre-defined tests whereby a
25 particular test may be selected. Position sensors 696 may be provided to provide input to the controller 628 as to the actual position of the drive carriage 658 during the testing procedures.

The machine 620 may additionally include a transverse mechanism 100 and/or a rotation mechanism 102 for effecting relative movement between the
30 sample holder and friction surface in a direction different from the forward and reverse directions. Additionally or alternatively, the machine 620 may includes a

temperature control chamber (such as the chamber 700, discussed above) enclosing at least the friction surface 644 and the sample S whereby temperature can be controlled to simulate different temperature conditions. Another option is to include components (such as the tube 108, the reservoir 110, the pump 112, and the drain 114 of machine 20) to transfer water onto the friction surface 644 to simulate wet driving conditions. The processor 628 may also control the transverse/rotational mechanisms, the temperature chamber and/or the wetting components.

Although the invention has been shown and described with respect to a certain preferred embodiment or embodiments, it is obvious that equivalent alterations and modifications will occur to others skilled in the art upon the reading and understanding of this specification and the annexed drawings. In particular regard to the various functions performed by the above described integers (components, assemblies, devices, compositions, etc.), the terms (including a reference to a "means") used to describe such integers are intended to correspond, unless otherwise indicated, to any integer which performs the specified function of the described integer (i.e., that is functionally equivalent), even though not structurally equivalent to the disclosed structure which performs the function in the herein illustrated exemplary embodiment or embodiments of the invention. In addition, while a particular feature of the invention may have been described above with respect to only one of several illustrated embodiments, such feature may be combined with one or more other features of the other embodiments, as may be desired and advantageous for any given or particular application.

What is claimed is:

1. A friction test system (20, 120, 320, 520, 620) comprising:

a carriage (58, 158, 358, 558, 658);

5 a friction surface (44, 144, 344, 544, 644);

a motion device (76, 134, 376, 576, 676) which causes relative movement between the carriage (58, 158, 358, 558, 658) and the friction surface (44, 144, 344, 544, 644) in at least a first direction;

a sample holder (62, 162, 362, 562, 662) mounted to the carriage (58, 158, 358, 558, 658) which holds a sample (S) in frictional engagement with the friction surface (44, 144, 344, 544, 644) during the relative movement between the carriage (58, 158, 358, 558, 658) and the friction surface (44, 144, 344, 544, 644) ;

15 a variable weight loading device (68, 168, 368, 568, 668) carried by the carriage (58, 158, 358, 558, 658) which loads the sample holder (62, 162, 362, 562, 662) so that a selected load can be applied to the sample in a direction normal to the friction surface (44, 144, 344, 544, 644);

a force measurement device (92, 192, 392, 592, 692) which obtains a measurement indicative of the frictional force resisting movement of the sample (S) as it is moved in the first direction; and

20 a processor (28, 128, 528, 628) which controls the motion device (76, 134, 376, 576, 676), controls the variable weight loading device (68, 168, 368, 568, 668) and/or records the measurements obtained by the force measurement device (92, 192, 392, 592, 692).

25

2. A friction test system (520, 620) as set forth in the preceding claim, wherein the processor (528, 628) further analyzes the measurements and compiles the results in the forms of tables and/or graphs.

3. A friction test system (520, 620) as set forth in the preceding claim, further comprising an output device (28a) which provides a readout of the compiled results.

5 4. A friction test system (520, 620) as set forth in any of the preceding claims, wherein the processor (528, 628) provides a library of pre-defined tests and a selection device for selecting a particular test.

10 5. A friction test system (620) as set forth in any of the preceding claims, wherein the motion device (676) causes relative movement between the drive carriage (658) and the friction surface (644) in a second direction opposite to the first direction so that the force measurement device (692) can obtain measurements indicative of the frictional force in forward and reverse directions.

15 6. A friction test system (520, 620) as set forth in any of the preceding claims, wherein the variable weight loading device (568, 668) is controlled by the processor (528, 628) to selectively vary the load applied to the sample.

20 7. A friction test system (520, 620) as set forth in any of the preceding claims, wherein the variable weight loading device (568, 668) is a fluid cylinder that can be moved to different positions to selectively vary the load applied to the sample (S).

25 8. A friction test system (520, 620) as set forth in any of the preceding claims, further comprising a temperature control chamber (700) enclosing the friction surface (544, 644) and the sample (S) whereby temperature can be controlled to simulate different temperature conditions.

30 9. A friction test system (520, 620) as set forth in any of the preceding claims, further comprising a plurality of friction elements representing different friction surfaces and wherein a selected one of the friction elements is removably

supported relative to the carriage (558, 658) to provide the friction surface (544, 644) whereby the friction element can be interchanged with other friction elements for providing respective different friction surfaces.

5 10. A friction test system (20, 120, 320, 520, 620) as set forth in any of the preceding claims, further comprising a second motion device (100, 200, 400; 102, 202, 402) for effecting relative movement between said sample holder (62, 162, 362, 562, 662) and the friction surface (44, 144, 344, 544, 644) in another direction different than said first direction.

10

 11. A friction test system (20, 120, 320, 520, 620) as set forth in the preceding claim, wherein the other direction is rotation about an axis perpendicular to the friction surface (44, 144, 344, 544, 644).

15

 12. A friction test machine (20, 120, 320, 520, 620) as set forth in either of the two preceding claims, wherein the other direction or another direction is transverse to said one direction.

 13. A method of measuring the coefficient of friction between a sample
20 (S) and a friction surface (44, 144, 344, 544, 644) with the friction test system (20, 120, 320, 520, 620) of any of the preceding claims, said method comprising the steps of:

 mounting a sample (S) in the sample holder (62, 162, 362, 562, 662); and
 activating the motion device (76, 134, 376, 576, 676) to cause relative
25 movement between the carriage and the motion device (76, 134, 376, 576, 676)
 in the first direction; and

 recording measurements obtained by the force measurement device (92, 192, 392, 592, 692);

 wherein said activating and said recording steps are performed by the
30 processor (28, 128, 528, 628).

14. A friction test machine (20, 120, 320, 520, 620) as set forth in any of the preceding claims, further comprising a water source (110) and a pump (112) which transfers water from the source onto the friction surface (44, 144, 344, 544, 644) whereby the force measurement device (92, 192, 392, 592, 692) can
5 obtain measurements indicative of the frictional force in wet conditions.

15. A method of measuring the coefficient of friction between a sample (S) and a friction surface (44, 144, 344, 544, 644) with the friction test system (20, 120, 320, 520, 620) of the preceding claim, said method comprising the steps of:
10 mounting a sample (S) in the sample holder (62, 162, 362, 562, 662);
pumping water onto to the friction surface (44, 144, 344, 544, 644); and
activating the motion device (76, 134, 376, 576, 676) to cause relative movement between the carriage (58, 158, 358, 558, 658) and the motion device (76, 134, 376, 576, 676) in the first direction.

15

16. A friction test system (620) comprising:
a drive carriage (658);
a friction surface (644);
a motion device (676) which causes relative movement between the drive
20 carriage (658) and the friction surface (644) in a first direction and a second opposite direction;
a sample holder (662) mounted to the drive carriage (658) which holds a sample (S) in frictional engagement with the friction surface (644) during the relative movement between the drive carriage (658) and the friction surface (644);
25 a variable weight loading device (668) which loads the sample holder (662) so that a selected load can be applied to the sample (S) in a direction normal to the friction surface (644);
a force measurement device (692) which obtains a measurement indicative of the frictional force resisting movement of the sample (S) as it is moved in the
30 first and second directions thereby obtaining measurements indicative of the frictional force in the forward and reverse directions.

17. A friction test system (620) as set forth in the preceding claim, wherein a sample carriage (660) is attached to the drive carriage (658) via linear bearings and wherein the sample holder (662) is mounted to the sample carriage (660).

5

18. A friction test system (620) as set forth in the either of the two preceding claims, wherein the base (622) includes a pair of guide rods (656) on which the drive carriage (658) is mounted and guided for movement and wherein the motion device (676) includes a motor (678) which rotates a lead screw (680) for linearly moving the drive carriage (658) along the guide rods (656).

10

19. A friction test system (620) as set forth in the preceding claim, wherein the lead screw (680) is positioned parallel with and between the guide rods (656).

15

20. A friction test system (620) as set forth in any of the three preceding claims, wherein the force measurement device (692) is secured to the sample carriage (660).

21. A friction test system (620) as set forth in any of claims 16-20, further comprising a processor (628), wherein the force measurement device (692) is a load cell that provides output signals indicative of frictional forces resisting movement of the sample (S); wherein the output signals of the load cell are provided to the processor (628) which processes these signals to provide a measurement of the friction characteristics of the sample (S) being tested on the friction surface (644).

20

25

22. A friction test system as set forth in any of claims 17-21, wherein the variable weight loading device (668) is carried by the sample carriage (660).

30

23. A friction test system as set forth in any of claims 17-22, wherein the sample holder (662) comprises a post (664) that is guided by suitable bearings in the sample carriage (660) for vertical movement perpendicular to the friction surface (644) and a sample mount (666) attached to the lower end of the post (664) to which the sample (S) is removably attached.

24. A friction test system (620) as set forth in the preceding claim, wherein the variable weight loading device (668) is attached to the upper end of the post (664).

25. A friction test system (620) as set forth in any of claims 16-24, further comprising a lifting device (70) to lift the sample holder (662) away from the friction surface (644) between testing procedures.

26. A method of measuring the coefficient of friction between a sample and a friction surface with the friction test system of any of claims 16-25, said method comprising the steps of:

mounting a sample (S) in the sample holder (662); and
activating the motion device (676) to cause relative movement between the drive carriage (658) and the friction surface (644) in the first and second direction.

27. A method as set forth in the preceding claim, wherein the activating step includes programming the motion device (676) to move the drive carriage (658) repeatedly in a reciprocating manner to collect friction data.

28. A method as set forth in the preceding claim, further comprising the step of averaging together the measurements obtained by the force measurement device (676) during the reciprocating movement.

29. A method as set forth in any of the three preceding claims, wherein the motion device (676) is operated at different speeds to provide a range of sliding velocities.

5 30. A friction test system (520) comprising:
a carriage (558);
a friction surface (544);
a motion device (576) which causes relative movement between the carriage (558) and the friction surface (544) in at least a first direction;
10 a sample holder (562) mounted to the carriage (558) which holds a sample (S) in frictional engagement with the friction surface (544) during the relative movement between the carriage (558) and the friction surface (544);
a variable weight loading device (568) carried by the carriage (558) which loads the sample holder (562) so that a selected load can be applied to the
15 sample (S) in a direction normal to the friction surface (544);
a force measurement device (582) which obtains a measurement indicative of the frictional force resisting movement of the sample (S) as it is moved in the first direction; and
a temperature control chamber (700) enclosing the friction surface (544)
20 and the sample (S) whereby temperature can be controlled to simulate different temperature conditions.

31. A method of measuring the coefficient of friction between a sample and a friction surface with the friction test system of the preceding claim, said
25 method comprising the steps of:

mounting a sample (S) in the sample holder (562);
controlling the temperature chamber (700) to simulate a temperature condition; and

30 activating the motion device (576) to cause relative movement between the carriage (558) and the motion device (576) in the first direction.

32. A method as set forth in the preceding claim, wherein the controlling step includes controlling the temperature chamber (700) to simulate a winter temperature condition and/or controlling the temperature chamber (700) to simulate a summer temperature condition.

AMENDED CLAIMS

[received by the International Bureau on 7 June 2001 (07.06.01);
original claims 1, 16 and 30 amended; remaining claims unchanged (3 pages)]

1. A friction test system (20, 120, 320, 520, 620) comprising:
a carriage (58, 158, 358, 558, 658);
5 a friction surface (44, 144, 344, 544, 644);
a motion device (76, 134, 376, 576, 676) which causes relative movement
between the carriage (58, 158, 358, 558, 658) and the friction surface (44, 144,
344, 544, 644) in at least a first linear direction;
a sample holder (62, 162, 362, 562, 662) mounted to the carriage (58,
10 158, 358, 558, 658) which holds a sample (S) in frictional engagement with the
friction surface (44, 144, 344, 544, 644) during the relative movement between
the carriage (58, 158, 358, 558, 658) and the friction surface (44, 144, 344, 544,
644) ;
a variable weight loading device (68, 168, 368, 568, 668) carried by the
15 carriage (58, 158, 358, 558, 658) which loads the sample holder (62, 162, 362,
562, 662) so that a selected load can be applied to the sample in a direction
normal to the friction surface (44, 144, 344, 544, 644);
a force measurement device (92, 192, 392, 592, 692) which obtains a
measurement indicative of the frictional force resisting movement of the sample
20 (S) as it is moved in the first linear direction; and
a processor (28, 128, 528, 628) which controls the motion device (76, 134,
376, 576, 676), controls the variable weight loading device (68, 168, 368, 568,
668) and/or records the measurements obtained by the force measurement
device (92, 192, 392, 592, 692).
25
2. A friction test system (520, 620) as set forth in the preceding claim,
wherein the processor (528, 628) further analyzes the measurements and
compiles the results in the forms of tables and/or graphs.

14. A friction test machine (20, 120, 320, 520, 620) as set forth in any of the preceding claims, further comprising a water source (110) and a pump (112) which transfers water from the source onto the friction surface (44, 144, 344, 544, 644) whereby the force measurement device (92, 192, 392, 592, 692) can
5 obtain measurements indicative of the frictional force in wet conditions.

15. A method of measuring the coefficient of friction between a sample (S) and a friction surface (44, 144, 344, 544, 644) with the friction test system (20, 120, 320, 520, 620) of the preceding claim, said method comprising the steps of:
10 mounting a sample (S) in the sample holder (62, 162, 362, 562, 662);
pumping water onto to the friction surface (44, 144, 344, 544, 644); and
activating the motion device (76, 134, 376, 576, 676) to cause relative movement between the carriage (58, 158, 358, 558, 658) and the motion device (76, 134, 376, 576, 676) in the first direction.

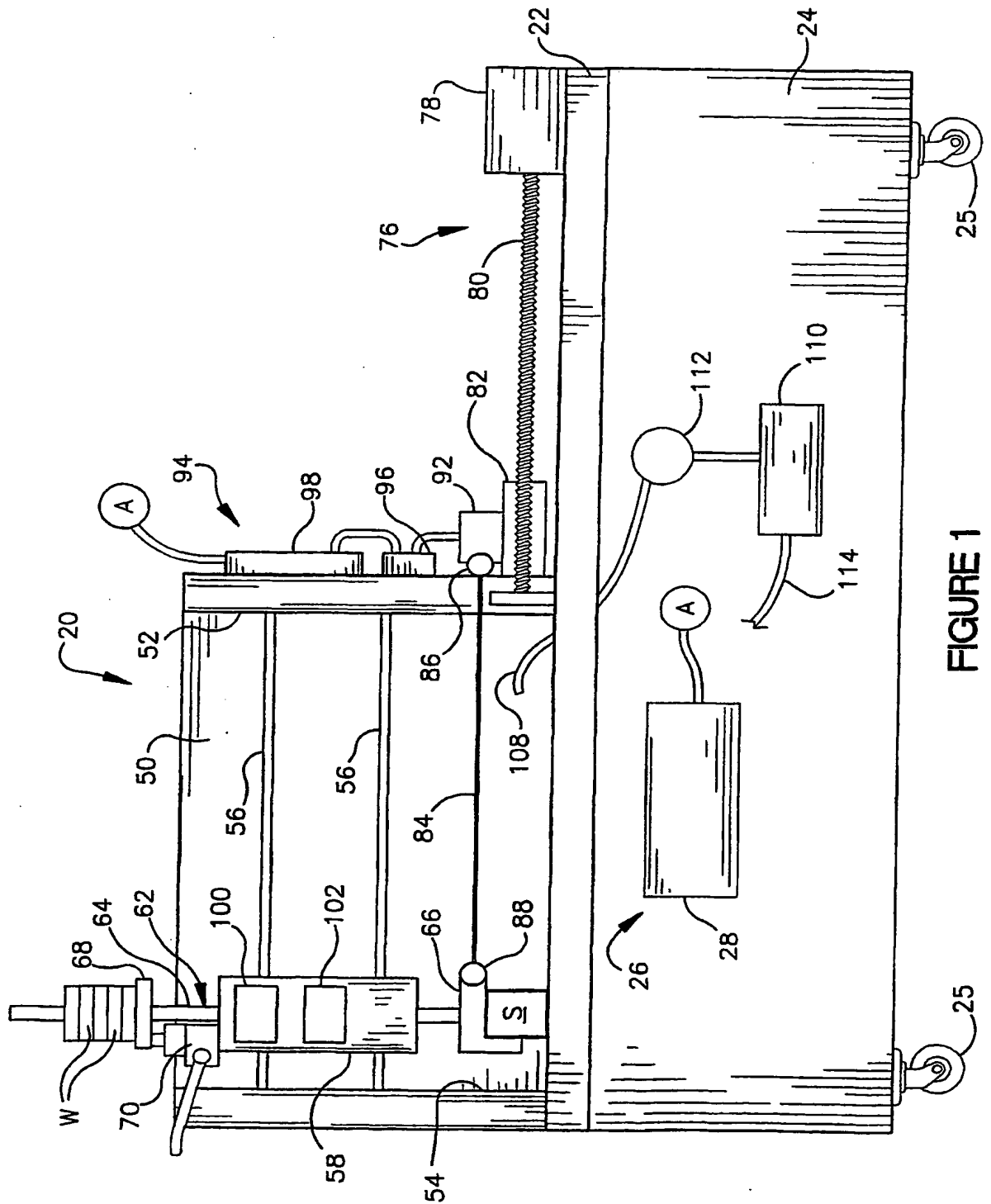
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16. A friction test system (620) comprising:
a drive carriage (658);
a friction surface (644);
a motion device (676) which causes relative movement between the drive
20 carriage (658) and the friction surface (644) in a first linear direction and a second opposite linear direction;
a sample holder (662) mounted to the drive carriage (658) which holds a sample (S) in frictional engagement with the friction surface (644) during the relative movement between the drive carriage (658) and the friction surface (644);
25 a variable weight loading device (668) which loads the sample holder (662) so that a selected load can be applied to the sample (S) in a direction normal to the friction surface (644);
a force measurement device (692) which obtains a measurement indicative of the frictional force resisting movement of the sample (S) as it is moved in the
30 first and second directions thereby obtaining measurements indicative of the frictional force in the forward and reverse directions.

29. A method as set forth in any of the three preceding claims, wherein the motion device (676) is operated at different speeds to provide a range of sliding velocities.

30. A friction test system (520) comprising:
- a carriage (558);
 - a friction surface (544);
 - a motion device (576) which causes relative movement between the carriage (558) and the friction surface (544) in at least a first linear direction;
 - 10 a sample holder (562) mounted to the carriage (558) which holds a sample (S) in frictional engagement with the friction surface (544) during the relative movement between the carriage (558) and the friction surface (544);
 - a variable weight loading device (568) carried by the carriage (558) which loads the sample holder (562) so that a selected load can be applied to the
 - 15 sample (S) in a direction normal to the friction surface (544);
 - a force measurement device (582) which obtains a measurement indicative of the frictional force resisting movement of the sample (S) as it is moved in the first linear direction; and
 - a temperature control chamber (700) enclosing the friction surface (544)
 - 20 and the sample (S) whereby temperature can be controlled to simulate different temperature conditions.

31. A method of measuring the coefficient of friction between a sample and a friction surface with the friction test system of the preceding claim, said
- 25 method comprising the steps of:
- mounting a sample (S) in the sample holder (562);
 - controlling the temperature chamber (700) to simulate a temperature condition; and
 - activating the motion device (576) to cause relative movement between the
 - 30 carriage (558) and the motion device (576) in the first direction.



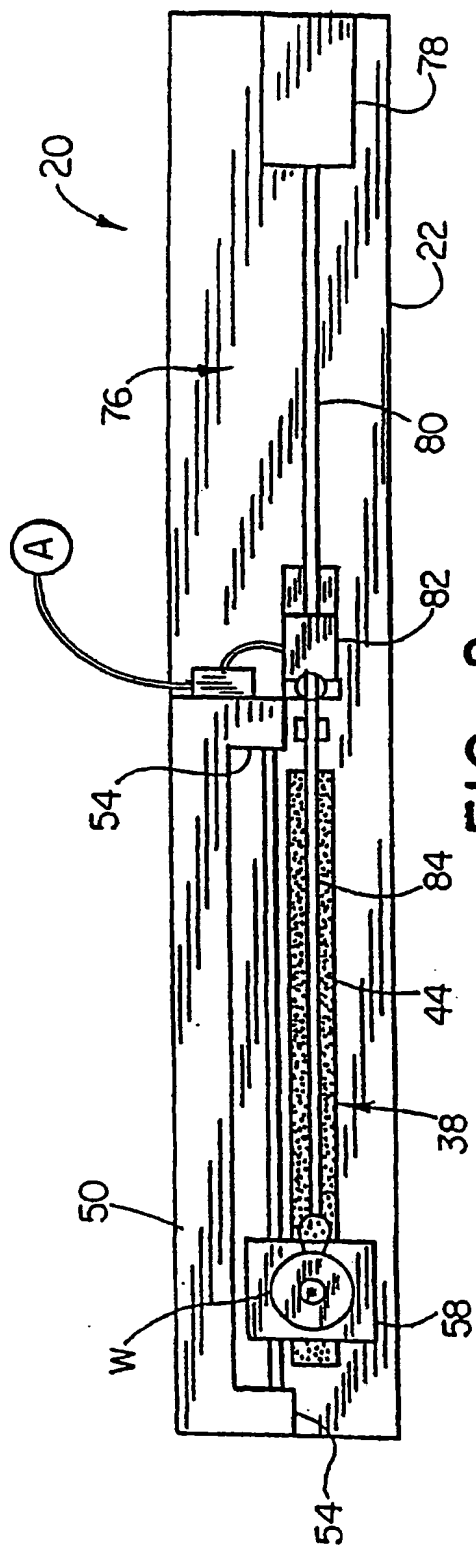


FIG. 2

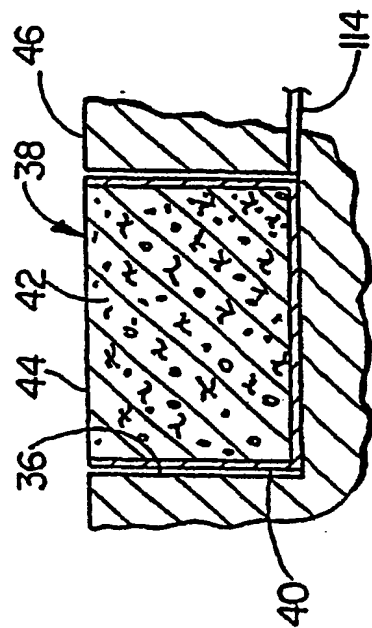
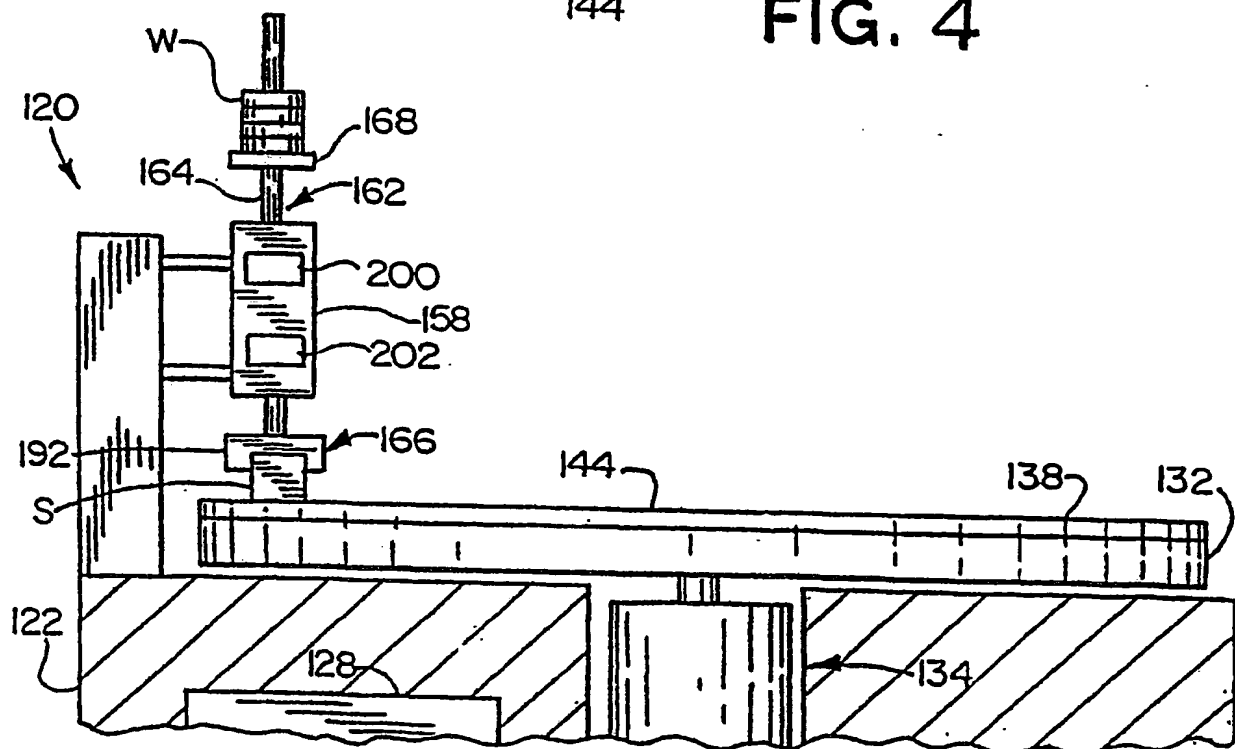
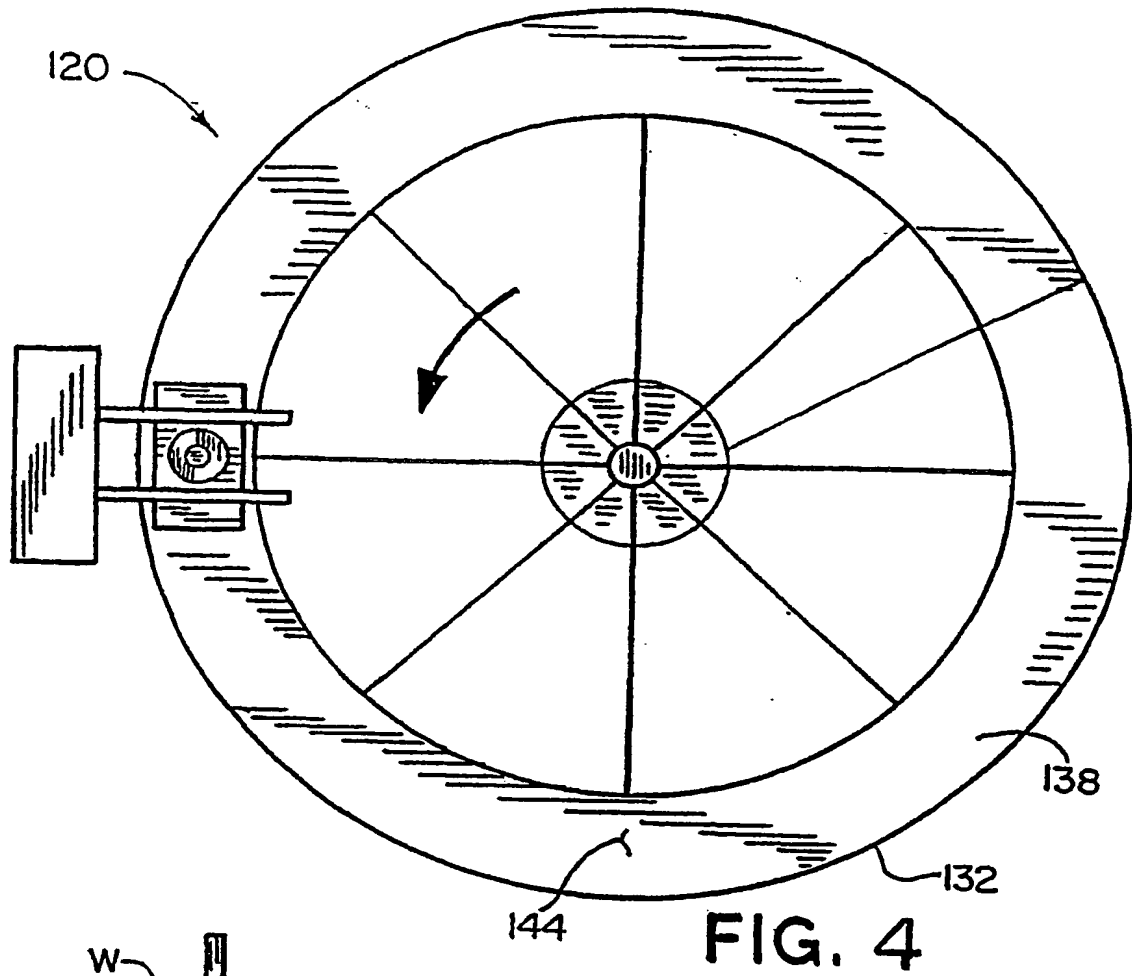
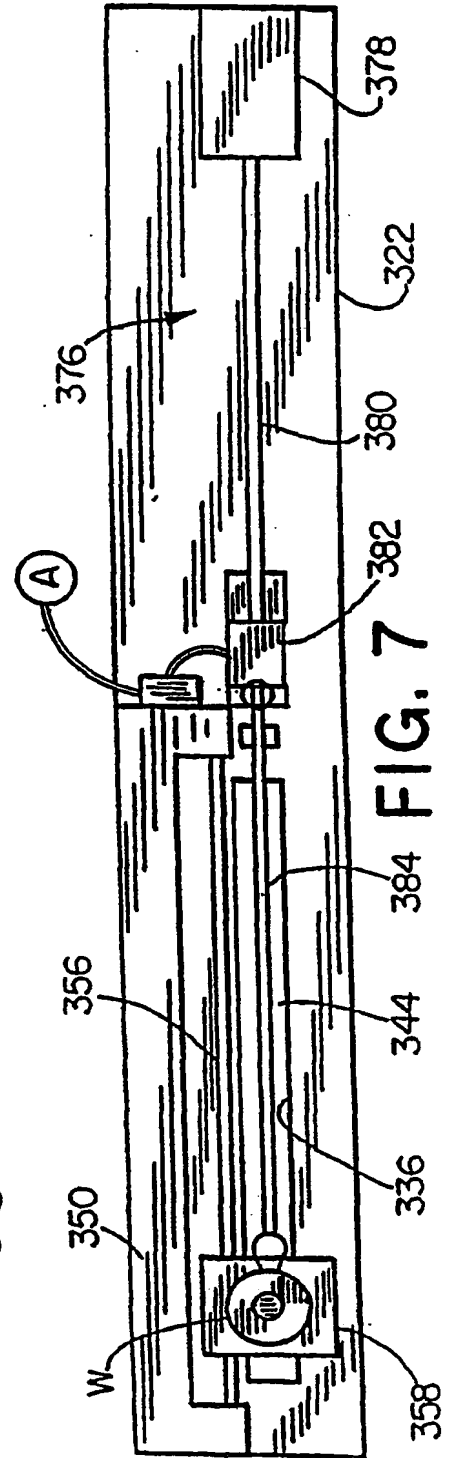
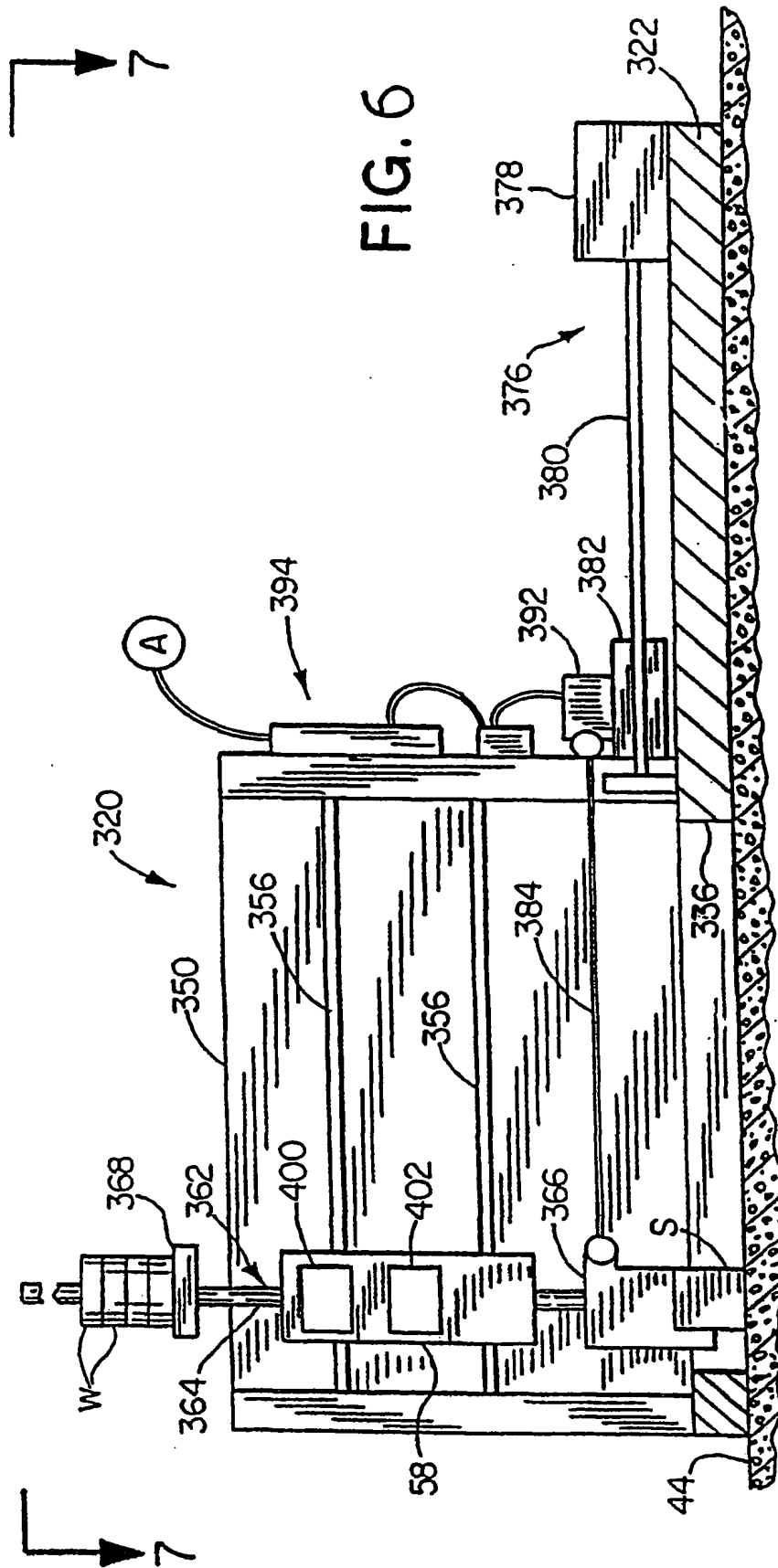


FIG. 3





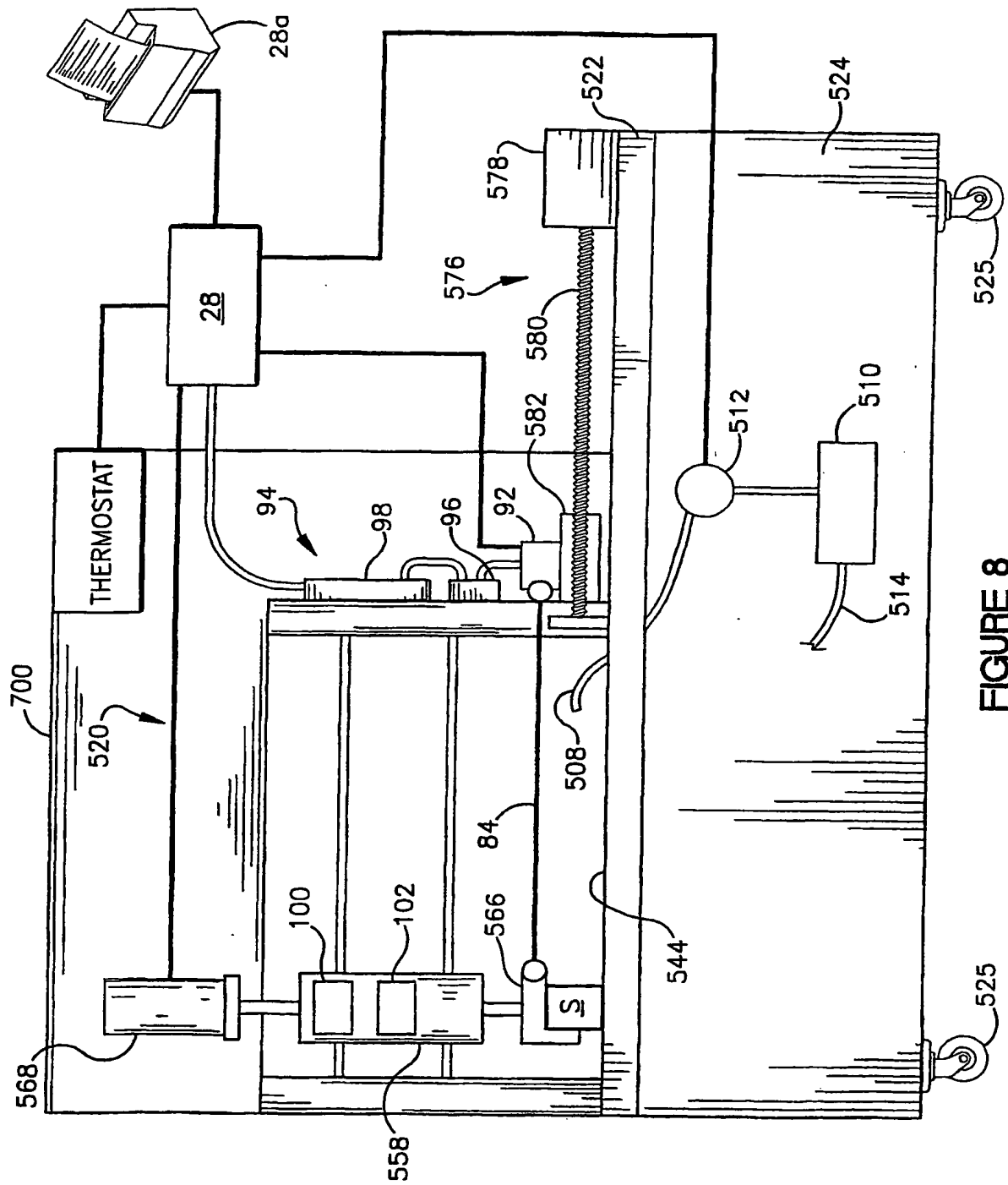
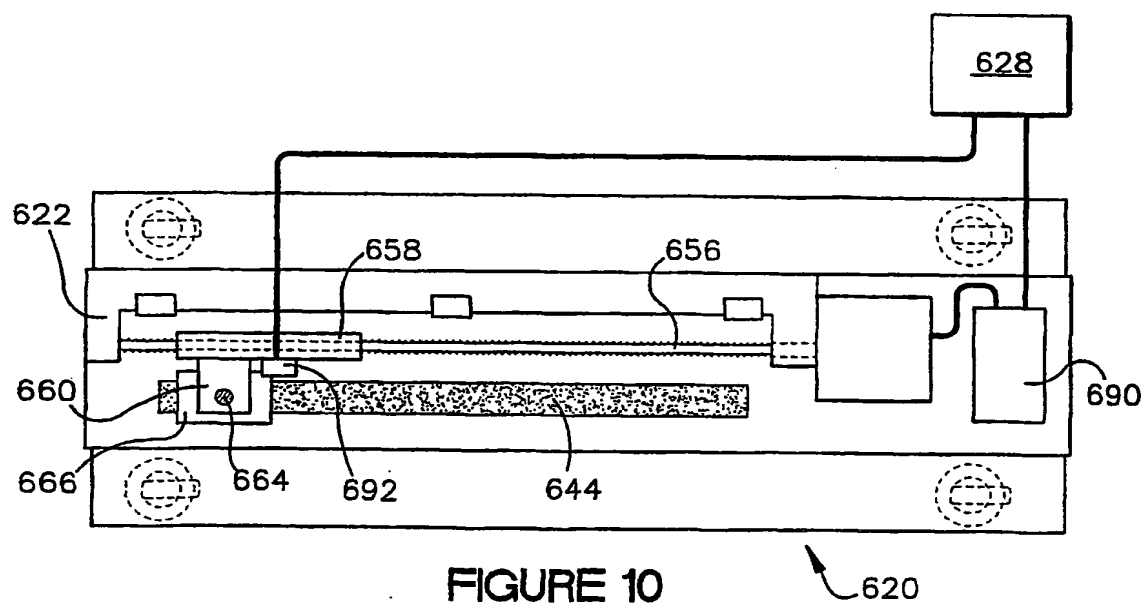
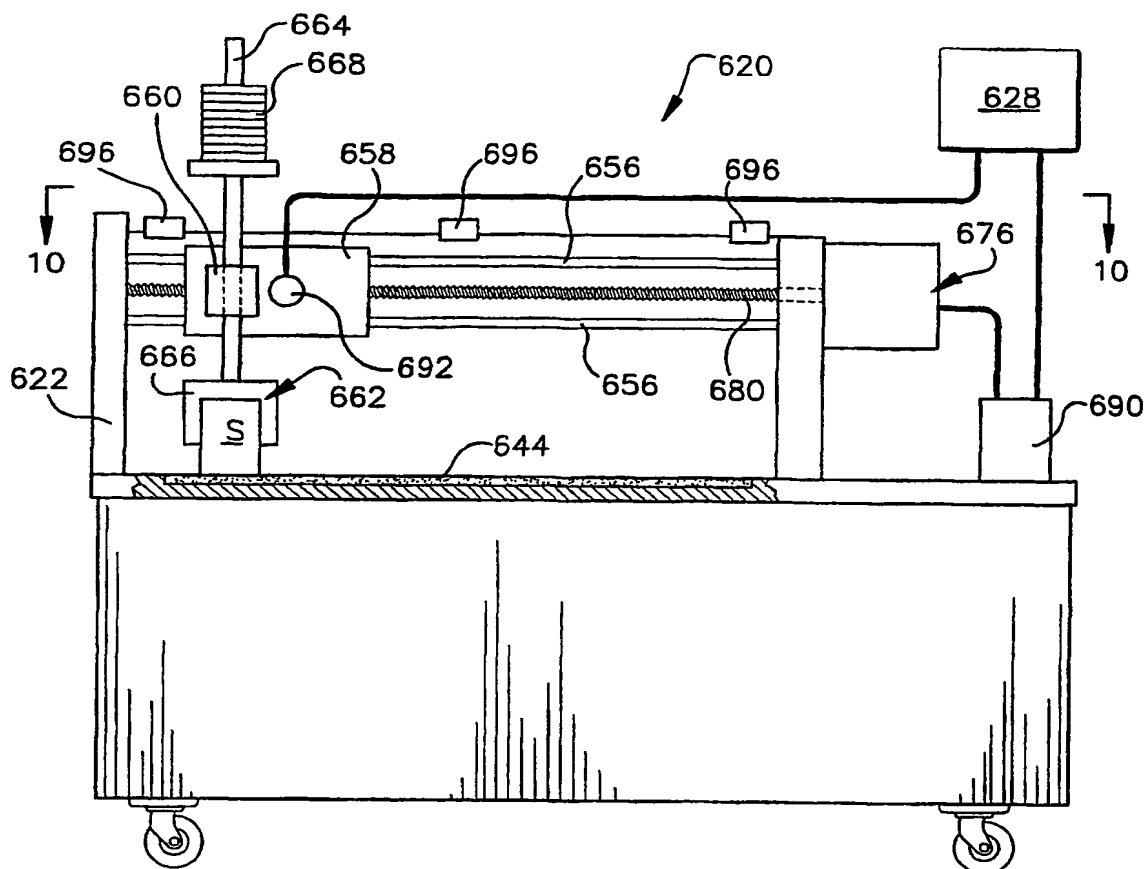


FIGURE 8



A. CLASSIFICATION OF SUBJECT MATTER
IPC 7 G01N19/02

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
IPC 7 G01N G01M

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

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C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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Y	column 4, line 19 - line 25 column 5, line 23 - line 25 column 6, line 2 - line 5 column 6, line 29 - line 57 column 7, line 15 - line 35 column 8, line 41 - line 50; figure 5 column 10, line 17 - line 21	20
X	— -/--	

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Date of the actual completion of the international search

4 May 2001

Date of mailing of the international search report

14/05/2001

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C.(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

Category *	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
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